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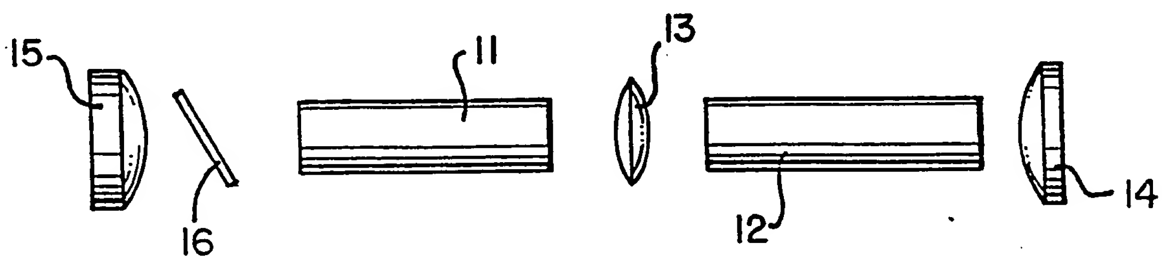
(54) Title: HIGH POWER ND:YLF SOLID STATE LASERS



(57) Abstract

A high power Nd:YLF solid state laser is constructed by placing a plurality of Nd:YLF solid state rods (11, 12) in series within a laser resonator. Each rod (11, 12) is mounted in a pumping chamber for providing laser action. A spherical lens (13) may be incorporated within the resonator as required for establishing with the resonator mirrors (14, 15) a large intra-cavity beam diameter. A cylindrical lens is provided within the resonator as a separate element or combined with the spherical lens (13) to compensate for astigmatism in the thermal focusing f Nd:YLF rods. Alternatively, the rods may be used in pairs with a half-wave plate between them to provide for compensation of astigmatism. A laser capable of high TEM_{00} mode output power may be achieved by these arrangements.

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HIGH POWER Nd:YLF SOLID STATE LASERS

BACKGROUND OF THE PRESENT INVENTION

Field of the Present Invention

The present invention relates to solid-state lasers and, more particularly, to improvements in solid state lasers having low thermal focusing and low thermal birefringence loss.

Background of the Present Invention

High power TEM_{00} solid-state laser output, either CW or Q-switched, is required for many commercial or research and development applications. Large active mode volume in the solid-state lasing crystal is a critical requirement in achieving this goal. Unfortunately, the active lasing volume in Nd-doped YAG (the most popular solid-state laser host) has been limited by its thermally-induced focusing (caused by large refractive index variation with temperature) and by thermal birefringence loss which increases quadratically with radial position in cylindrical laser rods. Therefore, CW TEM_{00} power over 30 watts remains unavailable from any commercial solid-state laser system today.

Certain characteristics of the crystal $Nd:LiYF_4$ (YLF) have been shown in recent studies to be advantageous. This crystal has very low thermal focusing and, because it is a birefringent crystal, its lasing output is naturally polarized and hence unaffected by thermal birefringence loss. In addition, Nd:YLF lasers have achieved TEM_{00} power outputs comparable to Nd:YAG with equivalent sized rods.

Thermal focusing in Nd:YLF Laser rods, although small, nevertheless is astigmatic, i.e. its magnitude and sign are different in the X and Y directions. This is conventionally corrected by utilizing a cylindrical lens to produce an utput beam that is circularly symmetrical. This cylindrical lens is in addition to the spherical lens used to expand the beam for large mode v lume.

An object of the present inventi n is to increase the

TEM_{00} power output of solid state lasers having low thermal focusing and low thermal birefringence loss.

A specific and further object of the present invention is to increase the power output of Nd:YLF solid state lasers.

Yet a further object of the present invention is to produce a circularly symmetrical output without the use of a cylindrical lens.

SUMMARY OF THE INVENTION

In accordance with the invention, a high power solid state laser comprises a laser resonator and a plurality of solid state laser rods mounted in pumping chambers. The rods are arranged in series and are constructed of a material having low thermal focusing and low thermal birefringence loss. Means are arranged within the resonator for establishing a large intra-cavity beam diameter and active volume, and, thereby, a high TEM_{00} laser output.

The laser rods are made of solid state Nd:YLF and the laser polarization is aligned along a crystal A axis to produce an output at 1053nm. A first Nd:YLF rod is mounted in a pumping chamber within the resonator. A second Nd:YLF rod is mounted in a second pumping chamber collinearly with the first rod. The laser energy output of one rod is focused relative to the other rod by lens and cavity mirror means so as to es tablish a large intra-cavity beam diameter and active volume and, thereby, a high TEM_{00} laser output.

Although arranged in series and aligned collin arly along a central laser axis, the rods are rotated 90° from one another about the laser axis. A half-wave plate is aligned collinearly along the laser axis positioned between the pair of rods and oriented to rotate the laser polarization by 90° thereby maintaining the appropriate laser wavelength output. As a result, the astigmatic beam of one rod is corrected by the astigmatic focusing of the second beam so that a circularly symmetrical output beam is cr ated.

F r a better understanding of the present invention, ref rence is made to the following description and accompanying

drawings while the scope of the invention will be pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Figure 1 is a representational view of the primary parts of the laser of the present invention;

Figure 2 is a block representation of the laser of Figure 1 operating in a Q-switched mode;

Figure 3 is a representational view of a Nd:YLF laser rod showing the astigmatism in the X and Y directions of the thermal focusing; and

Figure 4 is a representational view of two collinear Nd:YLF laser rods and a half-wave plate to produce circularly symmetrical output.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In order to enhance mode volume of a solid state laser, it is necessary to utilize completely the area of the laser rods so that intra-cavity beam diameter is expanded as much as is allowed by the limitations of rod diameter. However, in prior art YAG lasers this increase in beam diameter has also been limited by its thermally-induced focusing and birefringence loss. This limitation of beam expansion is overcome according to the present invention by the use of Nd:YLF rods, which have nearly zero thermal focusing and zero birefringence loss.

In Figure 1 there is shown a plurality of Nd:YLF laser rods placed in series inside a resonator in order to effectiv - ly increase the overall rod length so as to achieve a large active volume and, thereby, a higher TEM_{00} laser output.

Two such rods are shown in series within an arrangement 10. The rods may be identically sized and shaped and, for achieving TEM_{00} output, the rods are placed within a standard resonat r such as of th Quantronix 4000 series. The rods are 4X79 mm and are mounted in pumping chamb rs (not shown) in series within the res nat r.

In this s ri s arrangement, the rods are mount d

collinearly with convex lens 13 therebetween. The resonator includes high reflectance mirror 14 at one end and output mirror 15 at the other end. Element 16 represents an intra-cavity Brewster plate polarizer in order to maintain the polarization and therefore the wavelength of laser operation. The radii of curvature of convex reflective surfaces 14, 15 are 120 cm. These mirrors, together with lens 13, establish a large intra-cavity beam diameter. An actual Nd:YLF laser in accordance with the construction of Figure 1 has achieved a TEM_{00} laser output of 40 watts, larger than any reported value to date.

There is no reason to limit the design of the present invention to only two pumping chambers and numerous such chambers operating in series are within the scope of the invention subject only to available intra-cavity space and input power.

Although the thermal focusing in Nd:YLF laser rods is small, it is unfortunately astigmatic, i.e. its magnitude and sign are different in the X and Y directions. Fig. 3 shows a single Nd:YLF laser rod with the direction of output shown by the arrow in the Z direction.

The difference in magnitude and sign of the thermal focusing in the X and Y directions has conventionally been corrected by employing an intracavity cylindrical lens in addition to the spherical lens used to expand the beam for large mode volume. The output beam produced by the use of a cylindrical lens is circularly symmetrical in the X-Y plane. Another prior way of achieving this correction with the arrangement of Fig. 1 is to make lens 13 a compound cylindrical-spherical lens with the cylindrial axis aligned to compensate for the astigmatism.

When pairs of Nd:YLF laser rods are placed in series, an alternative to the conventional use of a intracavity cylindrical lens is possible. By rotating one of the two c llinear rods 90° relative to the ther the astigmatic focusing of one rod can be used to corr ct for the astigmatic focusing of the other. However, this rotation alone results in

alignment of the polarization of the 1053nm beam from the first rod along the crystal C axis in the second rod which axis is appropriate for laser oscillation at a different wavelength (i.e. 1047 nm). This potential problem is corrected as shown in Fig. 4 by placing a half-wave plate at the 1053nm laser wavelength that results in the rotation by 90° of the linear polarization in the first rod (shown as arrow 1) to the position shown by arrow 2 so that the laser beam is always appropriately polarized along crystalline A axis to maintain the laser wavelength the same in both rods. The crystalline A axis is shown in Fig. 4 as the Y-axis.

In this way, assuming uniform thermal focusing from rod to rod, the total intracavity focusing in the X and Y direction is equal for each pair of rods so that the astigmatism discussed above is compensated without the need for a cylindrical lens. A two-headed Nd:YLF Laser built without an intracavity cylindrical lens and in accordance with this embodiment has yielded over 30 Watts of TEM_{00} mode power in a circularly symmetrical beam. Naturally this technique can be expanded to more than two rods, so long as they are in pairs.

While the invention above has described only CW lasers, it is obvious that an intra-cavity Q-switch or mode lock modulator, either acousti-optic or electro-optic, activated by an appropriate drive can be added to produce a Q-switched or a mode locked laser output. Figure 2 illustrates, in block form, an arrangement wherein the invention described in Figure 1 may be operated in Q-switched or a mode-locked mode; Q-switch 21 is operated by driver 20 to create Q-switching action. Similarly, mode locked output can be produced using an intracavity mod - lock modulator.

While the foregoing description and accompanying drawings represent the pref rred embodiments of the pres nt inv ntion, it will b bvious to thos skilled in the art that vari us changes and modificati ns may b mad th r in without departing from th true spirit and scope of th pr s nt invention.

WHAT IS CLAIMED IS:

1. A high power TEM_{00} solid state laser comprising:

a laser resonator with pumping chambers;

at least two solid state laser rods mounted as coaxially in series the pumping chambers within the resonator, said rods being constructed of a material having low thermal focusing and low thermal birefringence loss; and

lens means within said resonator for expanding the beam to establish a large intra-cavity beam diameter and active volume, whereby a high TEM_{00} laser output is achieved.

2. The laser of claim 1, wherein said laser rods are constructed of Nd:YLF material.

3. The laser of claim 2, wherein said lens means for establishing a large intra-cavity beam diameter are a lens located between said two rods and resonator reflector surfaces at the ends of the resonator.

4. The laser of claim 3 wherein the lens is a compound cylindrical-convex lens with the cylindrical part aligned to compensate for astigmatic focusing of the laser rods.

5. The laser of claim 4 wherein the reflection surfaces are convex and have radii of curvature of about 120 cm.

6. The laser of claim 3 wherein the lens is a cylindrical lens aligned to compensate for astigmatic focusing of the laser rods.

7. The laser of claim 2 further including a Q-switch means located in the resonator and a driver means connected to the Q-switch means for operating the laser in a Q-switched mode.

8. The laser f claim 5 wherein the first and secon laser rods are shaped to be approximately 4 mm in diameter an 79 mm in length.

9. The laser of claim 2 further including a predetermined number of additional Nd:YAG rods mounted collinearly anc in series relationship within the resonator with appropriate lens means for focusing the laser energy of one rod with respect to the next so as to establish a large intra-cavity beam diameter in order tc achieve further increase in active volume and, TEM_{00} laser power output.

10. A high power TEM_{00} mode solid state laser comprising:

a laser resonator with pumping chambers;

at least a pair of solid state laser rods mounted in the pumping chambers and being arranged in series collinearly along a central laser axis, one of said pair of rods being rotated 90° from the other about the laser axis, said rods being constructed of a material having low thermal focusing and low thermal birefringence loss;

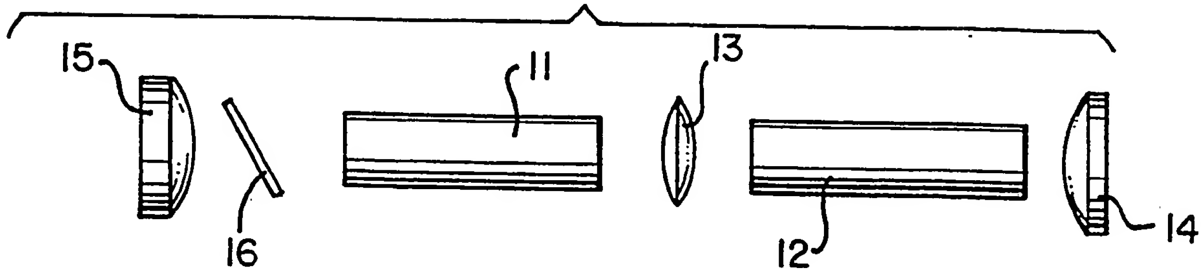
a half-wave plate at the laser wavelength aligned collinearly along the laser axis and positioned between the pair of rods for 90° polarization rotation; and

lens means within said resonator for expanding the beam to establish a large intra-cavity beam diameter and active volume, whereby a high TEM_{00} laser output is achieved.

11. The laser of claim 10, wherein said laser r ds are constructed of Nd:YLF material.

12. The laser of claim 11 further including a Q-switch means located in the resonator and a driver means connection to the Q-switch means for operating the laser in a Q-switched mode.

FIG. 1



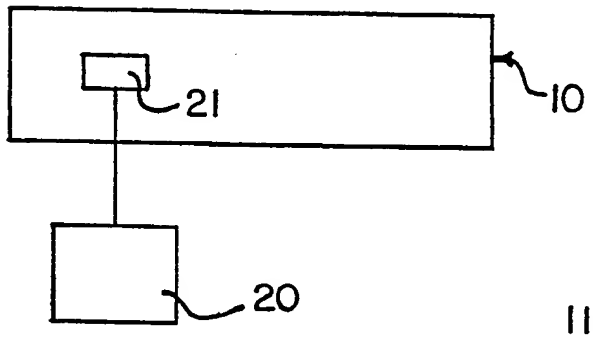


FIG. 2

FIG. 3

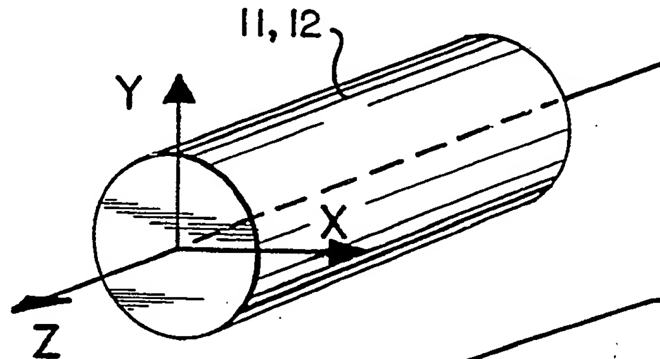
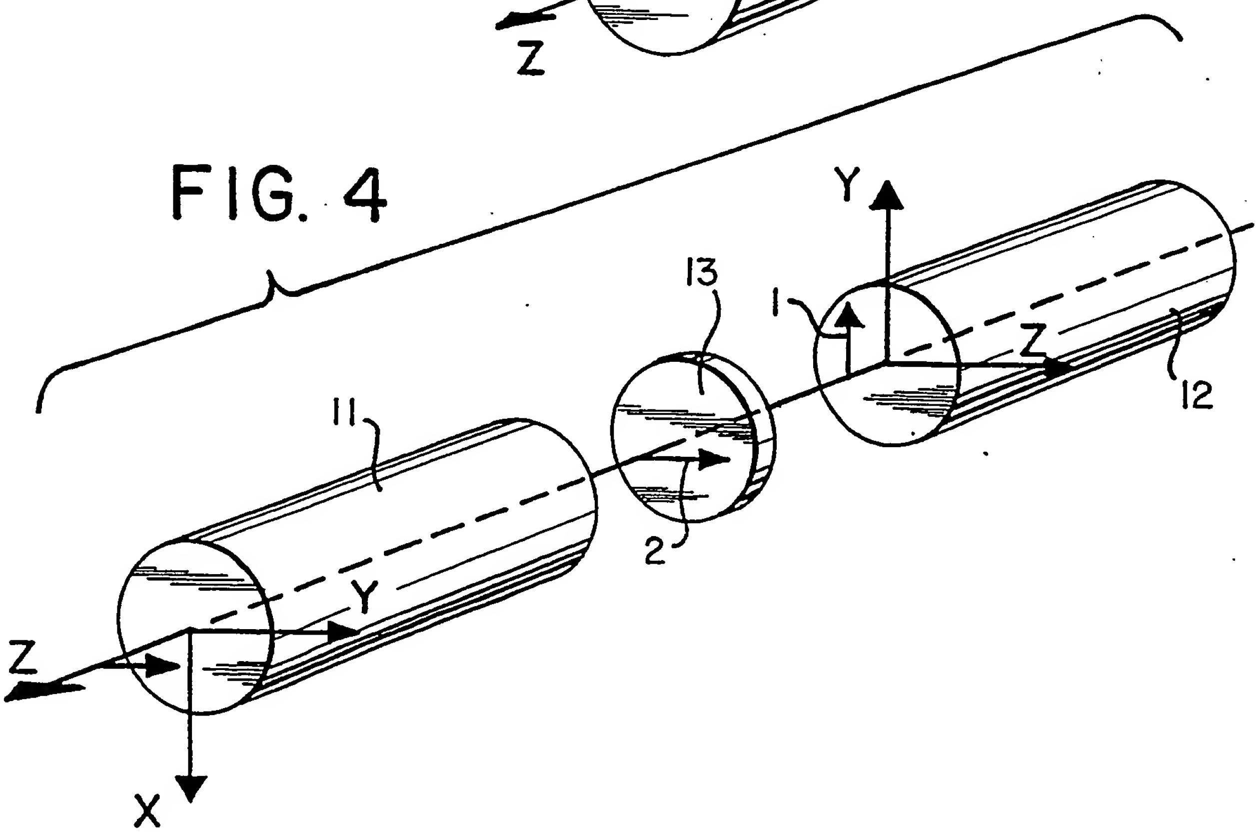


FIG. 4



INTERNATIONAL SEARCH REPORT

International Application No PCT/US90/02210

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5) H01S 3/00
U.S.CL. 372/33

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	372/97,33,68,40,41

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	US, A, 3,242,440 (KOESTER ET AL.) 22 March 1966 (Note figures 1 and 4).	1-12
A	US, A, 3,258,717 (KATZMAN) 28 June 1966 (See entire document).	
Y	US, A, 3,629,723 (SNITZER) 21 December 1971 (Note figure 6 and related disclosure).	10-12
Y	US, A, 4,352,186 (KUPPENHEIMER, JR. ET AL) 22 September 1982 (Note laser material being used).	2-9,11,12

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IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
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